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# The automatic computation for SUSY processes

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## Abstract

We have constructed a system for the automatic computation of cross-sections for the processes of the SUSY QED by the extension of the GRACE system including a Majorana fermion. The system has also been applied to another model including Majorana fermions, MSSM, by the definition of the model file.

## Introduction

It has been widely believed that there exists a symmetry called supersymmetry (SUSY) between bosons and fermions at the unification-energy scale. It, however, is a broken symmetry at the electroweak-energy scale. The relic of SUSY is expected to remain as a rich spectrum of SUSY particles, partners of usual matter fermions, gauge bosons and Higgs scalars, named sfermions, gauginos and higgsinos, respectively [1, 2, 3].

The neutral gauginos and higgsinos are Majorana fermions, which become the mixed states called neutralinos. Since anti-particles of Majorana fermions are themselves, there exists so-called ‘Majorana-flip’, the transition between particle and anti-particle. This has been the most important problem which we should solve when we realize the automatic system for computation of the SUSY processes.

In a recent work [4, 5], we developed an algorithm to treat Majorana fermions in the program package CHANEL [6] which has been developed for the numerical calculation of the helicity amplitudes. We have already possessed the GRACE system [7] which has been developed for the computation of the matrix elements for the processes of the standard model. The GRACE system automatically generates the source code for CHANEL, and includes the interface and library of CHANEL, and the multi-dimensional integration package BASES [8].

In the standard model, we already have such particles as Dirac fermions, gauge bosons and scalar bosons in the GRACE system. Thus we can construct an automatic system for the computation of the SUSY processes by the algorithm above in the GRACE system. In this work, we present the check list of the system.

### Majorana fermions into new GRACE

The method of computation in the program package CHANEL is as follows:

1. To divide a helicity amplitude into vertex amplitudes.
2. To calculate each vertex amplitude numerically as a complex number.
3. To reconstruct of them with the polarization sum, and calculate the helicity amplitudes numerically.

The merit of this method is that the extension of the package is easy, and that each vertex can be defined only by the type of concerned particles.

When we adopt the algorithm in Ref. [4, 5] for the implementation of the embedding Majorana fermions in CHANEL, the kinds of the Dirac-Majorana-scalar vertices are limited to four types:

- (1)  $\bar{U}\Gamma U$
- (2)  $U^T\Gamma\bar{U}^T$
- (3)  $\bar{U}C^T\Gamma^T\bar{U}^T$
- (4)  $U^T\Gamma^TC^{-1}U$

where  $U$ 's denote wave functions symbolically without their indices, and  $C$  is the charge-conjugation matrix. The symbol  $\Gamma$  stands for the scalar vertex such as

$$\Gamma = A_L \cdot \frac{1 - \gamma}{2} + A_R \cdot \frac{1 + \gamma}{2} \quad .$$

The vertices (2)~(3) are related to the vertex (1) which is the same as the Dirac-Dirac-scalar vertex in the subroutine of CHANEL. Thus we can build three new subroutines for the added vertices.

On the other hand, the GRACE system becomes more flexible for the extension in the new version called ‘**grc**’ [9], which includes a new graph-generation package. With this package, graphs can be generated based on a user-defined model. We have performed the installation of the subroutines above with the interface on the new GRACE system.

| Process              |  | Number of diagrams | Comment             | Check | Reference |
|----------------------|--|--------------------|---------------------|-------|-----------|
| <b>SUSY QED</b>      |  |                    |                     |       |           |
| $e^-e^- \rightarrow$ | $\tilde{e}_R^- \tilde{e}_R^-$          | 2                  | Majorana-flip       | OK    |           |
|                      | $\tilde{e}_L^- \tilde{e}_L^-$          | 2                  | in internal lines   | OK    |           |
|                      | $\tilde{e}_R^- \tilde{e}_L^-$          | 2                  |                     | OK    |           |
| $e^-e^+ \rightarrow$ | $\tilde{e}_R^- \tilde{e}_R^+$          | 2                  | Including pair      | OK    | [10]      |
|                      | $\tilde{e}_L^- \tilde{e}_L^+$          | 2                  | annihilation        | OK    | [10]      |
| $e^-e^+ \rightarrow$ | $\tilde{e}_R^- \tilde{e}_L^+$          | 1                  | Values are          | OK    | [10]      |
|                      | $\tilde{e}_R^+ \tilde{e}_L^-$          | 1                  | equal               | OK    | [10]      |
| $e^-e^+ \rightarrow$ | $\tilde{\gamma} \tilde{\gamma}$        | 4                  | F-B symmetric       | OK    |           |
| $e^-e^+ \rightarrow$ | $\tilde{\gamma} \tilde{\gamma} \gamma$ | 12                 | Final 3-body        | OK    | [11]      |
| <b>MSSM</b>          |  |                    |                     |       |           |
| $e^-e^- \rightarrow$ | $\tilde{e}_L^- \tilde{e}_L^-$          | 8                  | 4 Majorana fermions | OK    |           |
| $e^-e^+ \rightarrow$ | $\tilde{w}_1^- \tilde{w}_1^+$          | 3                  |                     | OK    |           |

Table I. The list of the tested processes.

## Results for tests

At the start for the check of our system, we have written the model file of SUSY QED. In this case, there is only one Majorana fermion, photino. Next we have extended the model file and the definition file of couplings for MSSM. The tests have been performed by the exact calculations with the two methods, our system and REDUCE. In Table I, the tested processes are shown as a list. The references in the table are not the results of the tests, but for help.

## Summary

We introduce a new method to treat Majorana fermions on the GRACE system for the automatic computation of the matrix elements for the processes of the SUSY models. In the first instance, we have constructed the system for the processes of the SUSY QED because we should test our algorithm with the simplest case. The numerical results convince us that our algorithm is correct.

It is remarkable that our system is also applicable to another model including Majorana fermions (*e.g.* MSSM) once the definition of the model file is given. We should compute the single-photon event from  $e^-e^+ \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \gamma$  [11], and the resultant single-positron (electron) event from the single-selectron production  $e^-e^+ \rightarrow \tilde{e}^\mp \tilde{\chi}_1^0 e^\pm$  [12] as soon as possible. It should be emphasized that the GRACE system including SUSY particles is the powerful tool for the purpose.

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